Precise Relative Motions of Formation Flying Space Vehicles

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ABSTRACT

This paper presents a comprehensive analysis of the relative motions between formation flying space vehicles in orbit about the Earth and Mars. Formation flying is proposed for spaceborne interferometry and new technology demonstrations in Earth orbit and in Mars orbit for in-situ navigation. To establish achievable control accuracies for these missions, dynamics in the orbit design space must be examined thoroughly. Dynamic forces considered are listed in Table 1. Relative motion characteristics are provided from LEO to GEO in Earth orbit and 100 km to 40,000 km at Mars. Co-planar and out-of-plane variations are considered with special emphasis on GEO orbits for separated space vehicle interferometry.

Table 1. - Dynamic Forces Considered for Relative Motion

N-Body:	All Planets, Sun, Moon
Earth Geopotential:	Up to 90x90 (JGM-3,MARS90)
Indirect Earth-Moon Oblateness:	2x2 Lunar Model
Solid Earth Tides:	IERS* (8 Constituents + Permanent Tide)
Earth Ocean Tides:	IERS* (14 Constituents)
Earth Rotational Deformation:	IERS* (User Defined C21 and S21)
Relativity:	Point Mass Earth + Lense-Thirring
Solar Radiation Pressure:	Umbra/Penumbra Shadow Model
Atmospheric Drag:	DTM, Daily Solar Flux, 3hr G-Index
Earth Albedo and Infrared Radiation:	2nd Degree Zonal Model

* IERS = International Earth Rotation Service

Applications

The simplest formation of two space vehicles with the same altitude and inclination are examined for missions validating new technology and for existing space vehicles requiring sensor calibration with follow-on missions. These formations allow for autonomous non-cooperative operations and have coarse control requirements. A technology validation example is the New Millennium Program's Earth Orbiter-1 (EO-1) mission. EO-1 will fly one minute (~450 km) behind the Landsat-7 land imaging mission and carry a lighter weight, lower cost version of the Landsat multispectral imaging system. Image co-registration requires control of the along track orbit separation to six seconds (~45 km). Another example is the TOPEX/Poseidon follow-on mission called JASON-1. Formation flying in this case is required to cross calibrate the altimeters that provide the primary science measurements.

More complex is a co-planar formation with space vehicles at different altitudes. This analysis is pertinent for spaceborne interferometry missions. Analysis of the relative motions is crucial to understanding the control requirements for such missions. In addition, out-of-plane or inclination differences are considered to allow for additional source target opportunities.

Finally, a constellation of space vehicles in several orbits differing only in the longitude of the ascending node is considered. Both Earth and Mars constellations are examined. Application of the relative motions is useful for developing autonomous navigation of the constellation as well as other space vehicles with radio tracking links to the constellation.

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